FUSION ENERGY SCIENCES ADVISORY COMMITTEE

U.S. DEPARTMENT OF ENERGY

PUBLIC MEETING MINUTES

Virtual Meeting via ZOOM
March 16, 2020

Fusion Energy Sciences Advisory Committee Meeting
March 16, 2020

The U.S. Department of Energy (DOE) Fusion Energy Sciences Advisory Committee (FESAC) convened on Monday, March 16, 2020 via teleconference from 10:00 a.m. – 4:00 p.m. Eastern Time (ET). The meeting was open to the public and conducted in accordance with the requirements of the Federal Advisory Committee Act. Information about FESAC and this meeting can be found at https://science.osti.gov/fes/fesac

Committee Members Present:

Dr. Don Rej (Chair), Los Alamos National Laboratory (LANL)
Dr. Troy Carter, University of California, Los Angeles
Dr. Robert Cauble, Lawrence Livermore National Laboratory (LLNL)
Dr. Diane Demers, Xantho Technologies, LLC
Dr. Ralph Izzo, Public Service Enterprise Group (PSEG)
Dr. Charles Kessel, Oak Ridge National Laboratory (ORNL)
Dr. Stephen Knowlton (Vice-Chair), Auburn University
Dr. Tammy Ma, LLNL
Dr. Rajesh Maingi, Princeton Plasma Physics Laboratory (PPPL)
Dr. Lorin Matthews, Baylor University
Dr. Gertrude Patello, Pacific Northwest National Laboratory (PNNL)
Dr. Susanna Reyes, SLAC National Accelerator Laboratory
Dr. Scott Parker, University of Colorado
Dr. Fred Skiff, University of Iowa
Dr. Philip Snyder, General Atomics
Dr. Thomas Sunn Pedersen, University of Greifswald
Dr. Paul Terry, University of Wisconsin
Dr. Erik Trask, TAE Technologies, Inc.
Dr. Brian Wirth, University of Tennessee

Committee Members Absent:

Dr. Mitchell Walker, Georgia Institute of Technology
Dr. Anne White, Massachusetts Institute of Technology (MIT)

Ex Officio Members Present:

Dr. Ellen Zweibel, University of Wisconsin
Dr. John Verboncoeur, Nuclear Plasma Sciences Society (NPSS), Michigan State University
Dr. Paul Wilson, American Nuclear Society (ANS), Oak Ridge National Laboratory

DOE Personnel

Dr. Jim Van Dam, Associate Director, Fusion Energy Sciences (FES), DOE Office of Science
Dr. Samuel Barish, Acting Designated Federal Officer for FESAC, FES

108 FES and fusion community members attended the meeting.

Undersecretary for Science Perspective, Mr. Paul Dabbar

Mr. Dabbar noted that the national labs are playing a role with the COVID-19 crisis, including opening up high performance computing (HPC) and light sources. He explained the role of the Federal Advisory Committees and thanked FESAC members for their commitment. Mr. Dabbar discussed three topics: the community planning process, the current state of the Office of Fusion Energy Science (FES), and budget appropriations.

The DOE Office of Science's budget and funding for the national lab complex is up 31%. Investment in the FES community has increased; the FY20 Appropriation included $671M for FES, a 19% increase over FY19. In FY18 and FY19, FES was at the high end of increased support from Congress. There is tremendous enthusiasm on Capitol Hill for discovery science in general and, from a budget point of view, for fusion energy in particular. Clean and sustainable energy discussions have increased in the last three years, and the positive effects of large investments in fusion energy by the private sector are being realized.

Despite financial improvements, the FES community has lacked the inclusiveness and cohesiveness evident in the High Energy Physics and the Nuclear Physics communities. That fragmentation led to the charge from Dr. Binkley to FESAC at the end of 2018. The charge put a two-stage process in motion: to undertake a new long-range strategic planning activity for the FES program and to carry out community-led activities with broad input as a foundation for FESAC's recommendations. FESAC enlisted the Division of Plasma Physics (DPP) of the American Physical Society (APS) to lead those community activities in the Community Planning Process (CPP). The report from CPP marks the completion of the first stage of the response to the charge.

Sir Steven Cowley assumed leadership of PPPL in summer 2018; under Dr. Cowley's leadership, the PPPL team is making great progress towards bringing NSTX-U back online. As a result of the significantly increased budgets for the community, DOE leadership has funded new facilities that had been planned for years. Since 2018, FES has taken important steps to increase engagement with the private sector fusion community through public-private partnerships. In summer 2019, FES launched the INFUSE (Innovation Network for Fusion Energy) program which provides grants to private enterprises to work with the national laboratories on research and development to solve problems arising from private fusion energy projects. The second round of INFUSE grants will occur in FY20. Currently, FES is responding to a request in the FY20 Appropriation bill to explain how it can operate another public-private partnership program based on NASA's commercial-off-the-shelf (COTS) program. After the FESAC meeting in December 2018, the National Academies of Science, Engineering, and Medicine (NAS) delivered its report on Burning Plasma research. The NAS report included a recommendation that the U.S. start a program for construction of a compact pilot plant that produces electricity from fusion at the lowest possible capital cost. DOE plans to ask the NAS to prepare a supplement to identify the steps necessary to build a pilot demonstration plant in the U.S., including essential research and development and ancillary infrastructure.

Mr. Dabbar expressed that he was impressed by the breadth and depth of the CPP report, saying the CPP accomplished the task DOE put before FESAC to acquire wide-spread input from a diverse community and with topics spanning the entire FES portfolio. Sixteen workshops, as well as numerous smaller meetings and conversations, were held across the country. Members of the scientific community produced over 300 new or revised initiatives or white papers for consideration. The CPP brought together scientists investigating astrophysics and other fields of discovery, plasma science, and scientists focused on building models and systems for fusion

power generation yielding robust, interdisciplinary discussions that have exposed participants to intriguing ideas outside their particular domains. The CPP helped build professional and personal relationships among scientists with varied interests who might not have otherwise come to know one another. Mr. Dabbar is optimistic that cross-cutting conversations that occurred during the CPP process will yield results and endeavors that are not readily apparent. He stated that the CPP generated a set of recommendations as a result of open discussions, respectful listening and inclusion, and various points of view. The CPP has engendered a set of priorities that represents true consensus. Mr. Dabbar hopes that the long-range strategic plan will realize widespread and cohesive support from this community as well as the broader scientific community.

The FES staff and Mr. Dabbar's deputy have shared evidence of the active leadership and engagement of relatively young scientists during the CPP process. Mr. Dabbar commended the APS for giving these individuals such an important role in the process. He expressed that the early career and young scientists and their fellow CPP participants have garnered DOE leadership's confidence in the plasma science and fusion energy community.

Mr. Dabbar concluded by expressing his appreciation to everyone who participated in the CPP and to those who played a leadership role in the process. He said that this community was given an urgent challenge and rose to the occasion, and expressed many thanks to everyone on behalf of DOE.

Discussion

Dr. Sunn Pedersen asked for a comment on the level of ambition in the plan and the degree to which FESAC should stay close to, or deviate away from, details in the CPP report. **Mr. Dabbar** expressed his enthusiasm for the report's level of ambition. He said that DOE is interested in options for pilot plants and demonstration plants in the U.S., and he encouraged the committee to think about next steps in terms of research and facilities that could be built in the U.S. He cheered the general tone and specifics in the CPP report, but emboldened the FESAC subcommittee to provide additional ideas. Mr. Dabbar conveyed that the subcommittee should make certain that the community consensus process is maintained.

Dr. Terry asked for suggestions on ways FESAC can make sure the consensus efforts have greater staying power and robustness to maintain momentum when DOE leadership changes occur. **Mr. Dabbar** said that the current DOE leadership benefitted from historical studies that laid out the facilities and areas of research to focus on. The Electron Ion Collider (EIC), for example, was based on long-range plans, Nuclear Physics' advisory boards, and other reports that consistently conveyed the importance of the science and the facilities enabling Mr. Dabbar to evaluate the suggestions and move forward. Having several reports that convey the same trajectory has great value; it provides consistency and cohesion. That support allows DOE leadership to go to Congress about, or make decisions on, what to build. It is important that everyone in the community is generally saying the same thing. This is only achieved by everyone working together and having an agreed upon direction and talking points.

Dr. Ma asked about maintaining program balance in light of Appropriation language concerning inertial fusion energy (IFE). **Mr. Dabbar** noted that it is more challenging to think about new versus old activities in a flat or downward funding environment. To a large degree, this is not a challenging time in DOE, and new projects have been moving forward. DOE has also been able to begin new projects, such as INFUSE and potentially a COTS program, and is beginning to consider a pilot plant. With regard to IFE, clearly there is interest from the

community about inertial confinement, and DOE has increased support with the allocation of additional money.

Dr. Kessel asked Mr. Dabbar to clarify the importance of partnerships between labs, universities, and industry in a fusion pilot plant and asked how the FESAC subcommittee should approach its deliberations in this area. **Mr. Dabbar** said that there are researchers in the private sector, and it is important to leverage multiple ideas. In terms of basic research, the U.S. invests more money than any country in the world to develop energy technologies. DOE encourages funded researchers and projects to work with private entities and move the technologies forward for public use. DOE has shared some ideas; for example, INFUSE was copied from GAIN (Gateway for Accelerated Innovation in Nuclear) from the Office of Nuclear Energy, and is developing public-private partnerships to replicate COTS from NASA. Mr. Dabbar encouraged FESAC to provide recommendations on how to increase collaborations and interactions.

FES Perspective, Dr. James Van Dam

Dr. Van Dam explained that the FES enacted FY19 budget was $564M, the FY20 appropriation is $617M, and the FY21 budget request is $425M. Dr. Van Dam shared updates on the accomplishments that are due to these healthy budgets and mentioned 10 funding opportunity announcements (FOA) – five of which have accompanying lab calls. An FOA in partnership with ARPA-E (Advanced Research Projects Agency – Energy) focuses on enabling technologies required for commercially viable fusion energy. Dr. Van Dam mentioned the DIII-D National Fusion Facility Upgrade, ORNL's SPI (shattered pellet injectors) testing, MIEs (major item of equipment) for a linear diverter simulator, the PLF (Petawatt Laser Facility) project, and the new Magnet Test Stand at LLNL. FES has partnerships in HPC with Japan on exascale for fusion. Other HPC efforts include an FES SciDAC (Scientific Discovery through Advanced Computing) activity focused on integration and whole-device modeling, and the PPPL-led WDMApp project in the Exascale Computing Project portfolio.

FES is contributing $7M of its FY19 funds for the NSF (National Science Foundation) /DOE partnership in basic plasma, non-neutral/dusty plasma, high-energy density plasma, and low-temperature plasma. The Advanced Laser Light Source in Quebec, Canada has joined LaserNetUS. In FY19, twelve awards in the INFUSE program were made to six private companies partnering with six DOE laboratories; in FY20, international companies are also eligible to apply.

Dr. Kathryn McCarthy was appointed as the new Project Director for U.S. ITER in November 2019. The sub-project-1 (First Plasma) for the U.S. ITER project is two-thirds complete. And more than 80% of the fabrication awards were made to U.S. companies, universities, and national laboratories. Civil construction at ITER is almost complete, and the assembly phase has begun. Examples of U.S. contributions to ITER include the Tokamak Cooling Water System and the Central Solenoid Module.

There are several new reports available, including "Advancing Fusion with Machine Learning" and "AI for Science." The CPP has concluded, and produced a substantive report. A draft report from the National Academies' Plasma Science 2020 decadal assessment is complete and is awaiting reviewer comments. The final NAS decadal report to Federal sponsors will be released in mid-April.

Dr. Van Dam closed with several updates. FES and ARPA-E formed a working group with the NRC (Nuclear Regulatory Commission); the NRC-DOE meeting to discuss this has been postponed. Mr. Dan Brouillette was appointed the new Secretary of Energy in December

2019. Dr. Nathan Howard of MIT received the 2019 Nuclear Fusion Award. The Spitzer Space Telescope, named after Professor Lyman Spitzer, Jr., founder of the PPPL, was retired on January 31, 2020 following 16 years of operation.

Discussion

None.

Report of the Community Plan for Fusion Energy and Discovery Plasma Sciences; Drs. Scott Baalrud, Nate Ferraro, Lauren Garrison, Nathan Howard, Carolyn Kuranz, John Sarff, and Wayne Solomon

Dr. Garrison began by expressing her appreciation to the community for participating in the CPP. She stated that the four goals of the CPP process were to produce strategic recommendations, both topical and cross-cutting, provide a near-term and long-term outlook, prioritize the recommendations, and deliver a report to FESAC by March 2020.

The process included three workshops at Madison, WI (July 2019), Knoxville, TN (October 2019), and Houston, TX (January 2020). The committee was organized by subgroups to produce recommendations in eight topical cross-cutting areas – Magnetic Fusion Energy (MFE), Fusion Materials and Technology (FM&T), High-Energy Density Physics (HEDP), General Plasma Science (GPS), Theory & Computation, Measurement & Diagnostics, Enabling Technology, and Workforce Development. Input from the fusion community was collected in two ways: advocacy groups that were self-organized groups of community members who provided input through white papers or initiative proposals, and expert groups made up of technical experts and led by program committee members who provided input via review of initiative proposals.

Dr. Solomon discussed the structure of the report, which was divided into three parts: DPS, FST (Fusion Science and Technology), and cross-cuts. DPS was primarily based on input from general plasma science and HEDP, while FST was based on input from MFE and FM&T including inertial fusion energy, and the cross-cutting opportunities came from all of the topical areas. The topical areas were merged (MFE + FM&T, GPS + HEDP, and IFE merged into FST + alternative MFE configurations) to form a coherent plan. The cross-cutting opportunities section has recommendations in four categories: theory and computation, measurement and diagnostics, enabling technology, and workforce, diversity, and inclusion.

The three major science drivers identified by DPS were explore the frontiers of plasma science, understand the plasma universe, and create transformative technologies. The three major science drivers from FST were control, sustain, and predict burning plasmas, handle reactor relevant conditions, and harness fusion power. Both the DPS and FST chapters are further organized into objectives and recommendations.

Dr. Howard discussed findings and recommendations for Fusion Science and Technology. The FST community embraces a mission-driven program to establish the basis for the commercialization of fusion energy in the U.S. The goal of the fusion pilot plant is to demonstrate both technical feasibility and commercial viability. The three deliverables of the pilot plant are to produce net electricity, establish capability, and demonstrate safe production and handling of tritium. Currently, the tokamak is the leading concept, but stellarators, inertial fusion, and other alternates could lead the effort.

FST is organized by science drivers, strategic objectives, and program recommendations. The three program recommendations are to participate in ITER, pursue integrated modeling, and

develop diagnostics. There are three overarching recommendations, focused on burning plasma, fusion materials, and embracing innovation. Ranking was done using the Prioritization Assessment Criteria, which are the importance to the fusion pilot plant mission, the urgency, the impact of the investment, the use of innovation to lower cost, and the potential for U.S. leadership and uniqueness.

Dr. Kuranz discussed the findings and recommendations for Discovery Plasma Science. DPS' recommendations were guided by rank-ordered criteria: U.S. leadership, transformational applications, breadth, community engagement, and interdisciplinary applications. The chapter is organized into DPS-wide programmatic recommendations (Build, Support, and Collaborate) and three science drivers (explore the frontiers of plasma science, understand the plasma universe, and create transformative technologies). The Build recommendation calls for investment in new facilities, upgrading current facilities, and co-locating facilities. The Support recommendation includes steady funding, fundamental data needs, and science centers. The Collaborate recommendation focuses on expanding networks and partnerships.

Dr. Baalrud discussed the three science driver categories in DPS (1, 2, and 3). DPS 1 – explore the frontiers of plasma science has five objectives listed as DPS-A, -B, -C, -D, and -E. These objectives focus on intense light coupling (A), magnetic fields (B), plasmas far from equilibrium and at interfaces (C), strong coupling and quantum effects (D), and antimatter plasmas (E). DPS 2 – understand the plasma universe includes three recommendations listed as DPS-F, -G, and -H. These objectives focus on plasma interactions in the solar system (F), origin and effect of magnetic fields (G), and causes and consequences of phenomena (H). DPS 3 – create transformative technologies includes four objectives: DPS-I, -J, -K, and –L. The objectives focus on plasma-based technologies (I), advanced manufacturing (J), physical well-being of society (K), and secondary sources (L).

Dr. Sarff discussed the cross-cutting recommendations in Theory and Computation, Measurement and Diagnostics, Enabling Technology, and Workforce, Diversity, and Inclusion. The three recommendations in Theory and Computation focused on verification and validation activities, advanced scientific computing tools, and improvements to FES-funded codes and outputs. The three recommendations in Measurement and Diagnostics included advances in diagnostics development, generation of data and analysis tools and data management, and a forum to guide diagnostic work. Enabling Technology's five recommendations covered public-private programs, advanced materials and manufacturing, transformative enabling technology, enabling technology and development in designs, facilities, and networks, and mission critical enabling technologies. Workforce, Diversity, and Inclusion had three categories of recommendations, each with sub-recommendations. Category A – embrace diversity, equity, and inclusivity's sub-recommendations included engaging DEI (diversity, equity, and inclusion) experts, implementing new and updated policies, incorporating consideration and promotion of DEI efforts, creating an accessible environment, increasing funding for underrepresented groups, and creating parental leave policies. Category B – increase pathways to fusion sub-recommendations included student design competitions, post-undergraduate education options, BS/MS-level scientist employment, public-private BS/MS development programs, public-private fellowships, a summer internship program, and faculty development grants and opportunities. Category C – increase literacy of plasma science and fusion energy and improve student involvement had two recommendations to support a new public-facing website, and support pre-college outreach.

Dr. Ferraro discussed the remaining questions to be addressed within the FESAC subcommittee and summarized the CPP activity. The questions that remain to be resolved include the issues of cost, prioritization, program balance, and the tension between urgency and commercial viability. Community consensus exists to pursue all of the recommendations. FST concentrated on science and technology that leads to construction of a fusion pilot plant, while DPS focused on realizing the potential of plasma science to deepen understanding. The report contains recommendations that can be enacted in the near-term, with partners, and within a 10-year horizon. The CPP report recommended that the activity recur every 5-7 years to adjust the plan as needed.

Dr. Rej dismissed FESAC for lunch at 12:35 p.m. and reconvened the meeting at 1:15 p.m.

FESAC Discussions on the Report of the Community Plan for Fusion Energy and Discovery Plasma Sciences, Dr. Donald Rej, FESAC Chair, Los Alamos National Laboratory

Dr. Sunn Pedersen thanked the CPP co-chairs and mentioned that he had hoped for more ambitious accelerator discussions particularly in blue-sky scenarios. He asked the chairs to talk about why the report did not go further on the stellarator side, pointing out that items the CPP flagged – control, sustain, and predict burning fusion plasma – are well addressed by stellarators. Additionally, stellarators have a more predictable configuration than tokamaks. He also inquired about the innovative aspects of the program that will support the new tokamak. **Dr. Howard** pointed out that the report reflects opinions from the community, not the co-chairs' personal opinions. There were a number of inputs from the stellarator community, many of which are reflected in the final report, for example the quasi-symmetric stellarator. The tokamak is the current leading concept for the fusion pilot plant, but that does not preclude it from being a stellarator.

Dr. Carter raised the issue of endorsement and expressed concern that the CPP report may be seen as a final plan. He asked how the co-chairs will advertise and utilize the endorsements by the signatories. **Dr. Ferraro** explained that there are no specific plans, rather the signatures were collected to show community unity and support. No names will be used in association with any statement, rather the signatures are simply a way to gauge and quantify community support for what has been done already.

Dr. Terry asked two questions about the contrast between the DPS and FST structures in the report, specifically a hierarchy of projects within FST objectives, and if international context was purposely avoided in the CPP. **Dr. Ferraro** mentioned that the mix of activities was made very clear and evident in the DPS area, but consented that the report may not be as clear in FST. There was significant community input on the necessity of roles for all FST stakeholders, as well as a mix of projects. He stated that the program committee was asked to convene expert groups to address international context. **Dr. Kuranz** explained that the differences in the report were due to DPS and FST starting at different places.

Dr. Kessel asked about timeframes and how the FESAC subcommittee should interpret the vagueness in the timeframes. **Dr. Garrison** said that FST took inspiration from the NAS Burning Plasma report, setting rough goals for the fusion pilot plant in the 2040s. In general, FST heard the community express a sense of urgency on these activities. Some of the earlier iterations of the report naturally matched into near-term and follow-on actions, but as the final report took shape it became obvious that near-term actions had the most information and clarity.

In the final report, all of the recommendations are things the community believes could start immediately. She explained that timing issues are integrally connected with budgeting, and budgeting scenarios were out-of-scope. The purpose of future CPP's is to keep refining, altering, and building on the direction started by the community to correctly sequence the later steps. **Dr. Baalrud** stated that in DPS there are few timelines because of the broad range of material. Timelines for each item were a level of detail for which the committee was not ready. Where timelines were discussed, for example, in the recommendation of partnerships with other agencies, some of those partnerships are already well-established (i.e. NSF, NNSA (National Nuclear Security Administration)); in other places, they are not established at all. Therefore, the timeline is to request that FES start by organizing workshops and bringing the fusion community together with other application communities to investigate what partnerships might look like.

Dr. Knowlton commended the committee for providing ambitious vision, mission, and values statements. He asked the CPP co-chairs to comment on the mission need for NTUF (New Tokamak User Facility) and if the NTUF plan can be elaborated on in time for the FESAC report. **Dr. Solomon** pointed to the detailed appendix related to NTUF and the mission need. NTUF originated in the Knoxville meeting and had a series of potential mission requirements or capabilities that the community weighed in on. There was a clear distinction in the capabilities that would be appropriate for such a facility or were considered valuable. However, there was a dividing line on the emphasis reflected in the later incarnations of NTUF at the meeting in Houston and in the report. The detailed appendix also includes consideration of the international context. The recommendation behind NTUF is to establish the mission need details. If FESAC adopts that recommendation, that could be part of the community activity.

Dr. Izzo said, as a participant in the electric power sector, that he is encouraged by the eagerness to engage in industry partnerships and is impressed by the scope and sophistication of the report. He was troubled by the absence of a focus on carbon pressures, the timing of carbon pressures, and recognition of the importance of fusion to shift the power sector away from carbon dependence in the next 2-3 decades. **Dr. Garrison** explained that this was a topic of discussion in the focus groups; it was a common theme, especially for early career and graduate students. Fusion power is an idea that resonates in the community. There is an attempt, in the report, to embrace the urgency and desire to move forward with the solutions. However, there is still a bit of sensitivity on how to formulate statements that are related to climate change.

Dr. Zweibel noted that the DPP intentionally took a very hands-off attitude on the CPP, but is excited by the level of engagement and leadership in the process. She suggested that the DPP can support the report's objectives in association with DPP activities, for example, holding joint meetings, having activities at DPP, participation in committees, etc... She asked the community to think of ways that DPP can help. **Dr. Kuranz** thanked Dr. Zweibel for the suggestion and advised FESAC that stating this type of activity is something that the long-range planning committee should keep in mind.

Dr. Verboncoeur recommended that a more explicit connection between DPS and FST be made in the CPP report. For example, the benefits realized through some partnerships outside of the agencies have exceeded their investments. He speculated that there might be value in explicitly tying the two sections together. **Dr. Baalrud** explained that the cross-cuts make the connections more clear. He acknowledged that there may be benefit to having a separate chapter, but stated that the CPP came a long way towards merging different aspects of the topics and felt the coherence of the program was evident in the report.

Dr. Matthews commented that studying stars or solar wind may not be seen as immediately useful, but it does tie into the vulnerability of the energy grid and satellite systems to solar flares. DPS did not speak to those immediate impacts that that research can have on very disruptive problems that occur. She requested more emphasis be placed on this area of research.

Dr. Wilson asked if the structure of DOE, where FST resides within the organization, is part of the FESAC subcommittee's scope, and if the CPP discussed how that structure meshes with the recommendations in the report. **Dr. Carter** stated that the DOE structure is important to consider in the second phase. Being as generic as possible in the FESAC report recommendations will make these structural questions simpler to address. He assured FESAC that if there is a need to address the DOE structure, the subcommittee will specify that it should be investigated. **Dr. Kuranz** reminded FESAC that the CPP was tasked with gathering input from the entire community. She agreed that discussing where programs fit in the DOE structure is a Phase 2 activity.

Dr. Parker inquired if there might be room in the CPP report for leveraging the big initiatives such as artificial intelligence (AI), quantum information science (QIS), and exascale as these are places where DOE is investing enormously. **Dr. Kuranz** noted that there is an initiative on quantum matter and AI as well as a need for increased scientific computing capabilities and capacities. She suggested that those should be elevated in Phase 2. **Dr. Parker** added that there is enormous opportunity in exascale computing and utilizing those systems for AI and QIS. **Dr. Sarff** explained that yes, fusion can benefit from exascale. FES has new FOAs in this area. However, the community has said that not everything being done in exascale is appropriate to fusion energy and plasma science; there is a balance to be achieved between computing capabilities and capacity to meet the needs of the fusion and plasma science community. **Dr. Baalrud** pointed out that DPS-D has a specific connection to QIS – using ion-trapped plasmas as a possible avenue to quantum simulators.

Dr. Snyder asked the CPP committee to provide guidance to FESAC on priorities in a reduced budget and any specific elements that should be considered in a truly unconstrained scenario. **Dr. Solomon** noted that there was a significant amount of work on the down-select to arrive at activities and needs which are considered necessary to meet the objectives as specified in the missions of DPS and FST. Considering more constrained budget scenarios, FST provided and collected important information from which the CPP developed a set of values that were translated into prioritization assessment criteria. This provides a good framework for how to consider what might be de-scoped to take higher risk. Both the data and the community sentiment are there. **Dr. Baalrud** addressed the question from the DPS side. What is in the plan is truly blue-sky in the sense that implementing all of what is in the report, at full capacity, is well beyond what is likely to happen in any budget. There is plenty of room, when funds become available, to have a plan in place. For more realistic budget scenarios, the size of the recommended programs will need to be scaled to appropriately match the budget.

Dr. Rej asked about the expectations of the FESAC subcommittee in terms of prioritization, budgets, cost and schedule, and technologies. **Dr. Garrison** said that the community feels that items in the plan are all important and useful. She would like to see the FESAC subcommittee fit the different scale items together and support some breadth of research across as many of the items as possible. But, simply having the scale of those research efforts be tuned to what is in the budget and what is appropriate would be welcomed. **Dr. Howard** expressed pride in how far the CPP committee and the community got in this process. The CPP committee heard, throughout the process, a wariness of the impact of people's involvement. Dr.

Howard would like to see FESAC follow the community suggestions and the level of prioritization in the report, and use that to develop budget-constrained plans to ease some of the community's concerns. **Dr. Sarff** stated that the CPP process was modeled on High Energy Physics' P5 process. High Energy Physics, through the course of their planning process, managed to secure significantly increased budgets. The fusion community consensus is based on a broad spectrum of activities and the community working together. Dr. Sarff urged the FESAC subcommittee to keep these in mind and think about concepts, such as a balanced portfolio to maintain consensus and create the opportunity for investment by DOE and Congress.

FESAC Subcommittee on a Long-Range Strategic Plan for the FES Program, Professor Troy Carter, Chair, University of California, Los Angeles

Dr. Carter provided some context on the FES strategic planning activity, noting that this was the first time in a long time FES has had such a process, and the first time it has been carried out in such a broad way. The last Snowmass was held in 2002 and it was neither as broad, nor as ambitious, as this one. FESAC completed the last strategic planning activity in 2014. The 2014 plan was more focused, formed in a constrained process, and was unsuccessful in the end; there was no community consensus plan. The outside perspective at that time was that the FES community was fractured and characterized by in-fighting. High Energy Physics was in same situation in 2014, but the success of P5 made a difference. High Energy Physics took its process from Nuclear Physics and saw their budgets rise significantly because of the P5 report and the consensus presented from that community.

There are two phases to the FESAC charge, to (1) develop a consensus-based strategic plan for the Fusion Energy Sciences portfolio (led by CPP), and (2) take the input from the CPP to answer the FESAC charge on a long range strategic plan with three budget scenarios and specific items to address in the final report.

Going forward, the FESAC subcommittee will use the CPP report as the basis for its report. The subcommittee will continue to invite contributions and accept new information, sending out requests and targeted solicitations for community input. Additionally, Dr. Carter would like to adopt the CPP website infrastructure and hopes that the existing expert groups will be willing to provide additional information when requested.

The FESAC subcommittee has already met four times and discussed this activity and the framework for the process. The next meeting, on March 17, 2020, will be an opportunity for extended discussions with the CPP co-chairs and an NAS representative on the Burning Plasma report. There will also be presentations on other key NAS reports. At this meeting, the subcommittee will refine the process and begin its work. Weekly zoom meetings will continue, and the subcommittee plans to finish the report for an NAS-style peer review and ensure delivery in December 2020.

Regarding conflicts of interest, the subcommittee is not subject to the same rules as FESAC. The procedure to be followed is that the subcommittee will acknowledge and work around conflicts of interest as they arise, and will make generic recommendations rather than institution- or project-specific recommendations. However, conflict of interest rules will apply when FESAC approves the final report.

Discussions on the FESAC Subcommittee on a Long-Range Strategic Plan for the FES Program, Dr. Donald Rej

Dr. Wirth asked how FESAC will obtain budget estimates for facilities to comply with the charge request for three scenarios. **Dr. Carter** explained that the subcommittee first has to develop a framework on its process starting with prioritizing values and principles from the CPP report, especially for non-blue-sky scenarios. The subcommittee will get advice from people involved in critical decisions (CD) on costing. Projects that are close to CD-0, such as the LaserNet upgrade and the FPNS (Fusion Prototypic Neutron Source), may be good sources of costing. At the CD-0 level, the costing is simply a range that could potentially double. The subcommittee is looking for that kind of order-of-magnitude on the projects. While producing designs is impossible with the time constraints, refining the scope is achievable.

Dr. Patello appreciated the graphics in the CPP report that showed staging and connections, but missed graphics on the connection between topics that feed into one another. She commented that getting the staging correct with the timeline might help frame the 10 years and also help with budget scenarios. **Dr. Carter** agreed. He stated that the first task the subcommittee will take on is the blue-sky scenario in FST because it is a sequential process. The goal is to focus on the next 10 years while keeping in mind the value of the effort to look beyond that timeframe.

Dr. Knowlton asked how the subcommittee will address U.S. participation in ITER. **Dr. Carter** said that there has not been any discussion on that yet. There is a sense, in the CPP process, of wanting to focus on what is new and current. The CPP report does call out ITER and its importance, but there are still details to figure out. The subcommittee needs to think about the process of how to support ITER operations and consider how ITER will play into the timelines.

Dr. Trask recommended creating a one-page document of how rules will be applied to various budget scenarios, and how activities and projects will be prioritized in terms of mission need and value of investment. He stated that the rules should be objective and written down so everyone is clear on how prioritization decisions are being made. **Dr. Carter** agreed, stating that in the P5 report the principles for prioritization are front and center; the ground rules are laid out. There may be different rules for DPS and FST, but the subcommittee has to decide on the framework first and foremost.

Dr. Demers pointed out that the process of the strategic planning will include prioritization, sequencing, continuity of effort, and allocation of resources. She inquired if Dr. Carter had considered utilizing outside resources, such as existing techniques or non-profit organizations to help with strategic planning. She also asked why the subcommittee does not have any international representation. **Dr. Carter** acknowledged that there are individuals and entities that the subcommittee could bring in to help with the planning. As to international representation, there was a conscious decision to only have domestic representation on the subcommittee to make interaction among the members easier. However, the subcommittee intends to reach out internationally for input. While there is a tradeoff, Dr. Carter is cognizant of that issue. **Dr. Rej** added that the subcommittee may also want to consider the international DOE collaborations, emphasizing that there are domestic scientists who know what is happening internationally. **Dr. Carter** indicated that he is contemplating how to make sure FES is correctly positioned in the international context. In terms of other facilities accomplishing the mission that is being set forth, the subcommittee needs to think about that. It does not mean that the mission and the idea of the facility are bad; it is a question of how to execute it.

Dr. Howard commented on the use of expert groups and the structure from the CPP process, noting that the expert groups were run by a large number of people, not the chairs. He asked if Dr. Carter intended to ask these individuals to continue running the groups or if the subcommittee would run them. **Dr. Carter** is considering asking questions about particular initiatives that were not conveyed within the CPP report. He noted that the expert groups considered these initiatives, thought carefully about them, and provided feedback that may be useful to the subcommittee. However, specifics of this idea have not been determined. **Dr. Howard** mentioned that the expert groups came up with Strategic Blocks and suggested that these may be helpful. **Dr. Carter** recognized that the CPP Google site contains useful material, including white papers.

Dr. Terry pointed out that the subcommittee's report needs to address the exciting science from fusion at a high level so that there is support among the larger scientific community and the physics community. He noted that in the CPP report there is a split between DPS and FST. DPS is very science oriented, while the FST science drivers sound like programmatic mission elements. **Dr. Carter** acknowledged Dr. Terry's comment and stated that there are conflicts on both sides. For example, in DPS there is opportunity on the process and low-temperature plasma side; there is also a microelectronics initiative to connect to. There are applications that can change the world, and the subcommittee report must call these out clearly, but also carefully think about the audience that will read the report.

Dr. Demers offered an idea to consider within the final report – inconsistent funding, financial costs of non-uniform or slow technology development, and social and environmental issues associated with the benefits of fusion. **Dr. Carter** said that the ultimate driver of continuity is the budget cycle, which is hard to control. However, having a clear plan and strategy help Congress know what to act upon. The societal and environmental benefits will be woven into the report. Dr. Carter was compelled by the comments on climate change and other societal benefits and intends to put language addressing these into the report.

Dr. Sunn Pedersen asked to what degree, and by what method, all of FESAC will be involved in the process. **Dr. Carter** stated that in the current planning there is nothing specific about interactions with FESAC. However, there will be guaranteed interaction as a community member, and he will consider the possibilities that exist for involving FESAC.

Dr. Sunn Pedersen stated that the blue-sky budget scenario is meant for FES to demonstrate courage and articulate what the community is ready for. The community appears to prefer waiting to see what ITER is doing in terms of the tokamak, and waiting for additional confirmation from two experiments on the stellarator. He sought confirmation that the community is not ready to build a fusion pilot plant. **Dr. Garrison** confirmed that the community is saying that it is not ready to build a fusion pilot plant. She explained that some of the first pieces that came in to FST were the initiatives. In evaluating those initiatives, the expert groups were asked to think about a fusion pilot plant as a goal and work backwards from that to identify all of the gaps that remain (unanswered questions, technological gaps in their expert area). The FST chapter lays out actions that are needed to get to a pilot plant. Right now, even with unlimited funding, the community is not ready to break ground on a pilot plant. There are some research and science activities that need to occur first to reduce the risks. **Dr. Ferraro** added that there is a clear preference within the community to target a pilot plant that is economically viable within the U.S. market and technically feasible.

Dr. Knowlton recognized that the charge is driving the community to come to consensus. However, there is a limited amount of time to address budget issues, priorities, and sequencing. He asked how the subcommittee plans to obtain consensus given the restricted timeline and possible tensions in the community. **Dr. Carter** acknowledged that the long-range plan will be meaningless if it does not have community consensus. The problem comes with specificity; therefore, the subcommittee will try to be generic and leave flexibility in the recommendations. Dr. Carter's approach is to jump in, identify the problem points, and work through them.

Dr. Garrison noted that one cross-cutting section in the CPP report focuses on workforce needs. There are suggestions for new activities that have not been supported by FES in the past. She asked if DEI ideas, broader needs for expanding the workforce, bringing more people into the field, and making sure they are staying and having fulfilling careers, will be in the FESAC report or dealt with in other ways. **Dr. Carter** agreed that both DEI and a sustained and engaged workforce are extremely important for the health of the field. The recommendations in the CPP report have a place in the FESAC report because they enable the community to be successful in achieving its goals. There are several reports currently in process that amplify some of these recommendations. **Dr. Carter** anticipates that the FESAC subcommittee will pay close attention to those and include them as additional recommendations.

Dr. Kuranz asked how, and in what form, community input will be obtained. **Dr. Carter** said all options are on the table. It is essential to continue to engage with the community and secure those connections to maintain consensus. At the moment, the subcommittee is considering calls for white papers and virtual meetings to help facilitate this. It is not permissible to have FESAC review a draft before it gets to them, but the subcommittee can gather as much information as desired from FESAC members.

Dr. Barish, in response to Dr. Knowlton's question about consensus, pointed out that a lot of time was spent choosing members of the subcommittee. Those members were chosen both for their scientific and technical expertise as well as the respect they command in the fusion and plasma sciences community. The subcommittee members have two jobs: (1) make the important decisions on priorities within the two constrained budget scenarios, and (2) champion the report to their respective communities when it reaches a semi-final point. FES is depending on the subcommittee members to reach out to their communities to obtain consensus.

Public Comment

Dr. Allen Boozer, Columbia University, commented that it is important to have an exciting consensus report that is based on the current scientific situation and societal needs. Dr. Boozer made four points about CO_2, computational design, and stellarators. First, he said that the CO_2 issue defines the timeline for fusion (roughly 30 years), and that there are societal and financial costs that go with it (~ a few trillion dollars per year). If fusion is delayed for a year, it is costing society something of that order. Second, the cost of computational design is tiny compared to the cost of development and deployment, 2-3 orders of magnitude difference. Because computational design is trivial, the community should be doing that. Third, stellarators side step the critical physics engineering issues that tokamaks have and allow an aggressive computational design, which means very fast and very cheap. Fourth, there is a need to determine how attractive the design of the stellarator power plant could be given a constraint. That constraint is that multiple iterations of experiments are not required before proceeding to final design and construction. Generation of experiments generally means decades; multiple

generations of experiments cause a long delay. He pointed out that the time between splitting the nucleus to building fission powered submarines was 15 years; it is at least 15 years from now before the first deuterium-tritium experiments will be done on ITER.

Dr. Hantao Ji, PPPL, made a point that the community must have a credible and consistent plan in terms of cost and schedule. The fusion energy sciences community must overcome the history of fusion and ITER. The long-range strategic plan is an opportunity to restore and establish the much-needed credibility for fusion research and development. Dr. Ji noted that the subcommittee needs to have independent evaluations of cost and schedule of the various projects proposed in the CPP report.

Dr. Rej adjourned the FESAC meeting at 3:44 p.m.

Respectfully submitted
T. Reneau Conner, PhD, PMP, AHIP
Science Writer – ORISE/ ORAU

Certified as Correct by:

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Dr. Donald J. Rej,
FESAC Chair
Date June 1, 2020